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P A P E R

ON

SELF-REGULATING MECHANISMS OF THE
HUMAN BODY, WITH ESPECIAL REFERENCE
TO TEMPERATURE

BY

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Everyone is familiar with the fact that there are animals whose temperature is very little if at all above that of their surroundings, cold-blooded animals; and that there are others like ourselves which keep their temperature constantly several degrees above their surroundings. It is also a matter of common knowledge that any particular warm-blooded animal has the power of regulating his temperature so that it does not vary more than a fraction of a degree, while he is in health. Our first task is to enquire how this is effected. To put the matter briefly, we have fires in our bodies. Perhaps one of the most significant data of physiological science is that our food is burned up in such a way as to give the same chemical products as if it were burned in an ordinary furnace. Oil and sugar, for instance, become carbon dioxide and water. It is easy to show that sugar when eaten soon causes the giving off of an increased amount of carbon dioxide in the expired air. These facts were first clearly realised by Lavoisier, although Boyle and Mayow had come very near to the truth.

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But of course fuel is not always burned in fires for the purpose of giving heat alone. We call to mind that heat is but one form of energy, and just as we burn coal under a steam boiler for the purpose of getting mechanical work out of an engine, so the main purpose of the food we eat is to afford energy for muscular work. Part of the chemical energy of the fuel is in both cases converted to mechanical work and part appears as heat. We may note further that the human body has no other source of energy than that obtained from the combustion of food and there is perhaps no more important result of the investigations of modern physiologists than that which proves an equivalence between the energy taken in and that given out. Thus the human organism obeys the first law of thermodynamics, or the conservation of energy. It is a familiar fact that the value of food is expressed in terms of heat units, "calories," just as that of any other fuel.

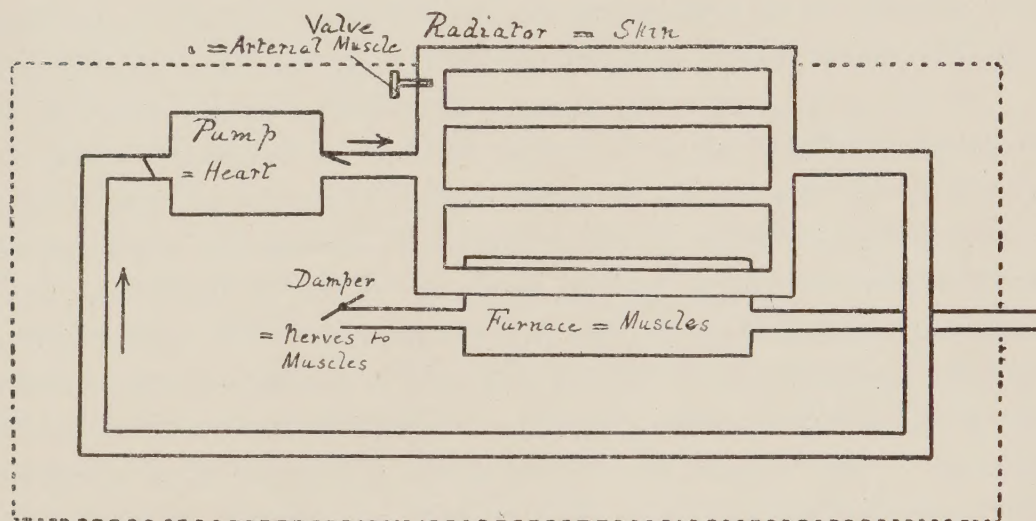
Since we are always producing heat, chiefly in the muscles, it is clear that, unless there were some means of getting rid of the excess, the temperature of our bodies would rise to a dangerous extent and our next task is to enquire into the means of regulating the process.

In the first place, we lose heat from the skin, and by the breath, chiefly the former. We lose it from the skin in three ways, partly by radiation to surrounding objects, partly by convection currents of warmed air, but the most effective of all is by evaporation of water in the sweat. It is important to remember that this evaporation of water is always going on, although it is only at times that there is visible moisture on the surface. If the air is very dry, and there is only a moderate degree of activity of the sweat glands, water may disappear as fast as it makes its way through the skin. It is needless to remark that the efficiency of the evaporation of water as a cooling agent is due to its very high latent heat of evaporation.

But now it may be asked, if the source of heat is mainly in the muscles and the place where it is lost is in the skin, how does it happen that there is a fairly even temperature throughout the body? No doubt the answer will occur to everyone. It is by means of the circulating blood, which is heated in one place, cooled in another.



The warm blood from the muscles is taken to the skin, cooled, and returned. Perhaps a diagram on the lines of a possible system of warming a house may help in realising the process. A pump may be used to circulate water through a branched system of pipes; one of these is exposed to the cool atmosphere, and may be called a radiator. This corresponds to the skin, while the pump represents the heart. Another of the branches passes through a furnace, equivalent to the muscles. It will be seen that the temperature inside the dotted space, that is the body, may be regulated either by a valve on the radiator, or by combustion of more or less fuel in the furnace. That a local cooling or warming of a part of the



circulation is capable of disposing of a large amount of heat from the body as a whole is shown by Leonard Hill's experiments on the results of immersing the hands in warm or cold water. It may be remarked incidentally that the curative effects of exposing the skin to the sun's rays are only rendered possible by the simultaneous cooling due to cold air or bathing in water. Otherwise, the internal temperature of the body would rise to a fever heat.

As remarked above, we can regulate the loss of heat in our scheme by adjustment of a valve on the radiator. The physiological mechanism which corresponds to this is the muscular coat possessed by all the small arteries of the body, including those of the skin. This muscle is arranged in the form of rings, so that

when it shortens, the lumen of the tube is narrowed. The process is under the control of nerves which are given off from the central nervous system (brain and spinal cord). We meet here with one of the great integrating systems of the body, the other one being the blood circulating in the vessels. But before making further reference to this, it is well to recall a circumstance that has been pointed out as regards the regulation of temperature. In temperate climates, the cold that has to be guarded against comes from the outside, whereas the heat is produced in muscular exercise within the body. Hence, information of the former is mainly derived from nerves in the skin, which are sensitive to changes in temperature. These nerves convey messages to the brain and set up a process of co-ordination by which other messages are sent outwards to the blood vessels, the sweat glands, the muscles and also to the organs of respiration. Regulation by increase or decrease of muscular work is rather limited in its scope, since the heart and the respiratory muscles must always be at work. But muscular exercise is an excellent means of raising the temperature. There appears to be a special part or centre in the brain from which these various activities are controlled. The centre which regulates temperature is thus an example of the many other similar ones which act in co-ordinating and integrating the manifold bodily processes. The brain has often been compared to a telephone exchange, in that any part of the body, so far as supplied with nerves, can be put into communication with any other part. Indeed, the process which takes place in the nerve is most probably of an electrical nature.

On consideration of the fact that a rise of temperature is usually brought about by muscular activity, which warms the blood, it would be expected that some arrangement would be made by which the regulating centre is made aware of the temperature of the blood. It appears that such an arrangement exists in the centre itself. For, if it be warmed artificially, it is found that all the various cooling mechanisms already enumerated are set going; while if it is cooled, those which raise the temperature enter into activity. We see here one function of the second great integrating system, the blood. But perhaps an even more important charac-

teristic of this system is that of conveying not only fuel to the organs of the body, but also the oxygen to burn it. The former is picked up from the organs of digestion, while the latter is absorbed from the air taken into the lungs. This is owing to the red colouring matter (hæmoglobin) in the blood, which has the remarkable property of taking up oxygen at a pressure lower than that of the atmosphere and giving it up again at a still lower pressure, such as exists in the places where it is being consumed. Much more oxygen can be carried in this way than would be possible by solution in a watery fluid. Thus, in contrast to the nerves, which convey messages not in the ordinary sense of the word material, the blood actually carries ponderable substances, and may thus be compared to the mechanical transport of a city by means of carts and so forth. Perhaps a better comparison would be the distribution of water or gas in pipes.

A property of some practical importance is that hæmoglobin is saturated with oxygen at a pressure lower than that in the atmosphere. Now a room begins to feel badly ventilated long before the oxygen has fallen to such a level as to affect the amount carried in the blood. Similarly, the carbon dioxide rarely rises to such a degree as to affect respiration. The experiments made by Leonard Hill show that the feeling of "stiffness" may disappear if the air is merely set in motion by a fan, without being changed. It seems therefore that the chief part is played by some stimulation of nerves in the skin, which serves to keep the brain awake.

I pass on to refer briefly to another striking case of self-regulation in intimate relation with the process of combustion in the animal organism. When muscles and other organs which require a supply of oxygen for their activity are set to work, it is clear that they need not only an additional supply of oxygen but that the increased products of combustion must be removed. The chief of these latter is carbon dioxide. It is a familiar fact that muscular exertion brings about an increased rate and depth of respiration. This serves not only to supply the additional oxygen wanted, but also to get rid of the carbon dioxide. But the way in which the increase in the ventilation of the lungs is brought about exactly in proportion to the need at the time is perhaps not so well known.

The heat-regulating centre in the brain has been referred to as an example of the various similar centres for other purposes. Now, one of these centres controls the activity of the muscles which cause the entrance of air into the lungs by enlarging the cavity of the chest. We call it the "respiratory centre." This centre has the property of being set into greater activity by an increase of carbon dioxide in the blood passing through it, just as the heat-centre is by changes in the temperature of the blood. The respiratory centre is also to some extent sensitive to a deficiency of oxygen, but its response to carbon dioxide is of extraordinary delicacy. Physiologists have not yet been able to discover exactly what it is in the nature of the cells of the centre that makes them so sensitive, but it is in some way connected with the acidity of solutions of carbon dioxide. The adequacy of this property to ensure an increased supply of oxygen along with the elimination of excess of carbon dioxide is obvious, because the increase of ventilation involves both. It will also be clear that to obtain the full benefit of this accurate adjustment, the air breathed must not contain an excess of carbon dioxide.

In connection with this latter requirement, a word may be said as to the humidity of the air in relation to temperature control. The drier the air, the greater the rate of evaporation from the skin and the more effective the cooling produced. The discomfort of hot moist air is known to everyone. But of course there are limits of comfort, especially if the air is at the same time cold and dry. The well-known "katathermometer" of Leonard Hill serves as a useful indicator of the cooling properties of the air, in relation to its temperature.

The reference above to limitations reminds me that in the matter of loss of heat from the skin, a certain compromise must be permitted when the external temperature is very low. Although it would naturally be the most effective proceeding in such circumstances to cut off entirely the circulation through the skin, the result of doing this would be that the skin would be killed by cold and frost-bite would ensue. Accordingly, the normal response is by a slight dilation of the arteries, so that the fine capillary vessels receive a current of warm blood, red, owing to the full complement

of oxygen. The skin is red, not white, as it would be if the arteries were closed. But there is an interesting abnormal response to cold, in which the skin contains blood, but is cold. Its colour is blue, not red. This is due to a narrowing of the arteries, along with widening of the capillary channels. The current is very slow, so that the blood becomes cold and at the same time loses its oxygen, and becomes venous. It is of interest that such a state of the circulation has been found to play an important part in the production of the state of shock after injuries or surgical operations.

I have spoken of two great systems of integration, the nervous and the circulatory. But there is still another, to which much attention is being given at the present time. It will probably occur to many readers that no mention has been made of a common mode of inter-communication in cities, namely, the postal system. In this, actual material letters are conveyed, as in mechanical transport, but these letters are not themselves used as fuel, or in any way other than as messages, instructing certain things to be done. Thus, they partake of the characters of both the other systems. In the human organism, the internal secretions, chemical messengers, or hormones play the part of letters. They are actual chemical compounds produced in some organ or tissue, passed into the blood and thus carried to all parts of the body, but produce an effect only in particular places adjusted to respond to them. Letters also are only received at the address to which they are directed, although they pass many other houses. It is thought by some investigators that all the various kinds of cells produce each its own particular "chemical messenger," which has its action on other parts of the body, but up to the present we know of the definite existence of such substances in the case of special organs, such as the thyroid, the pancreas, and so on. The problem is a large and complex one and space does not permit of further discussion here.

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